# A Programmable Ni-Cd Recycler

## *Safely recharges and reconditions nickel-cadmium batteries and up to 10 cells of any capacity*

**By Peter A. Lovelock**

So many articles have been written about the care and feeding of rechargeable nickel-cadmium batteries that it is probably difficult to imagine anything new in this subject. As a heavy user of Ni-Cd batteries and cells, however, two

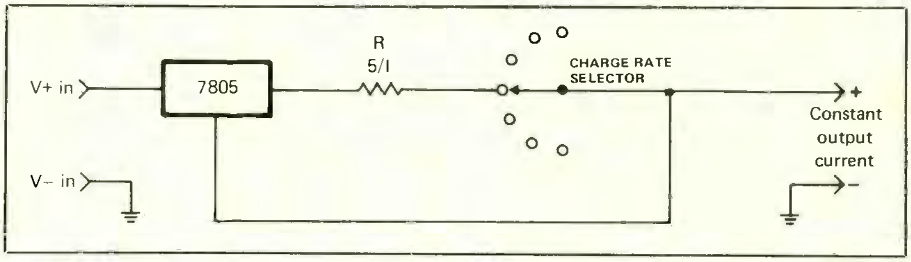
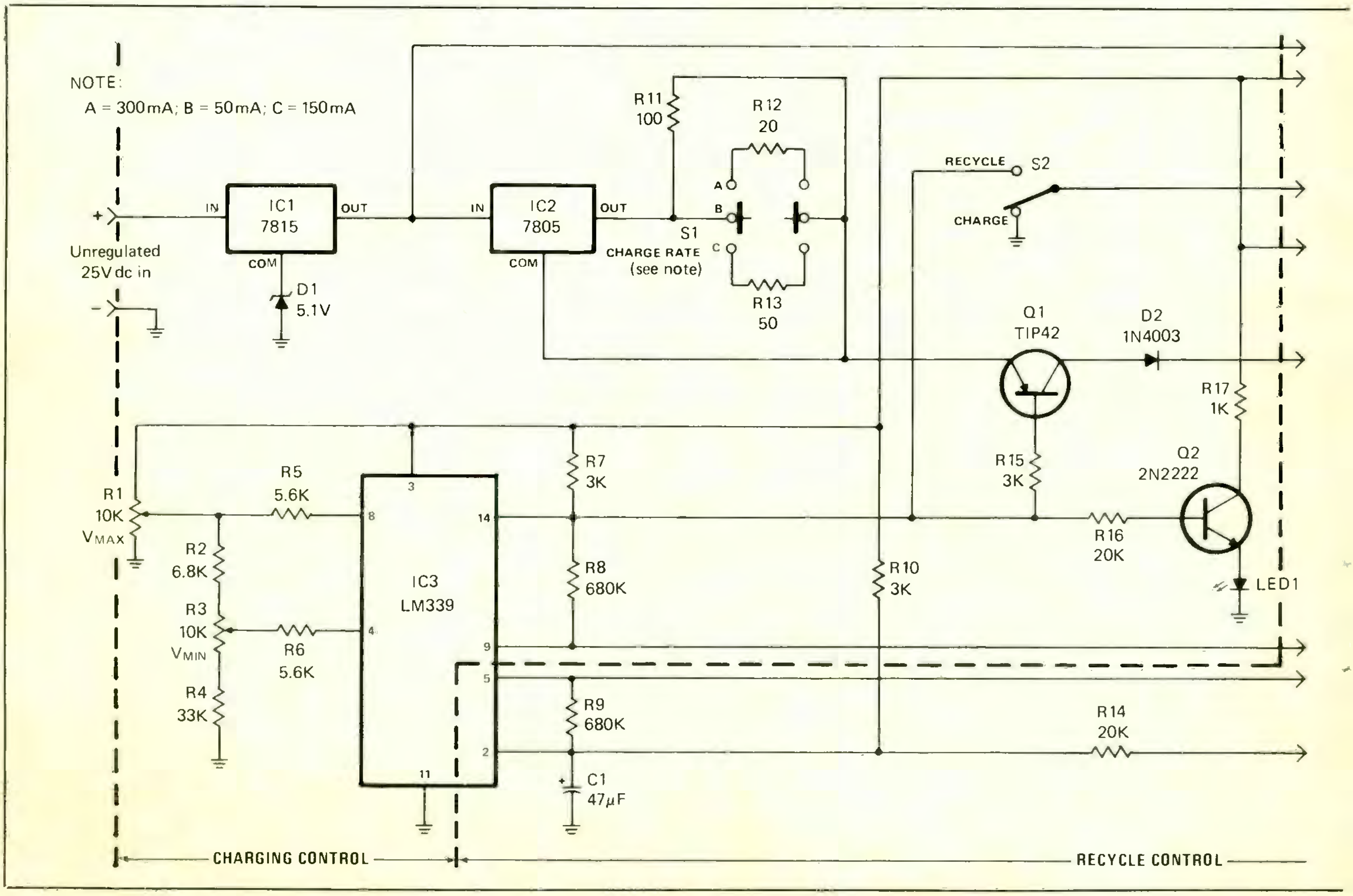



*Fig. 1. The basic constant-current charger circuit.*

*Fig. 2. Overall schematic diagram minus power supply.*



problems have always plagued me. One was the need to have a number of chargers around for the various voltage/capacity power packs I use. The other was the need to regularly "exercise" my Ni-Cd cells and batteries to eliminate the "memory" phenomenon that affects them when their charges are constantly "topped up" after partial discharge.

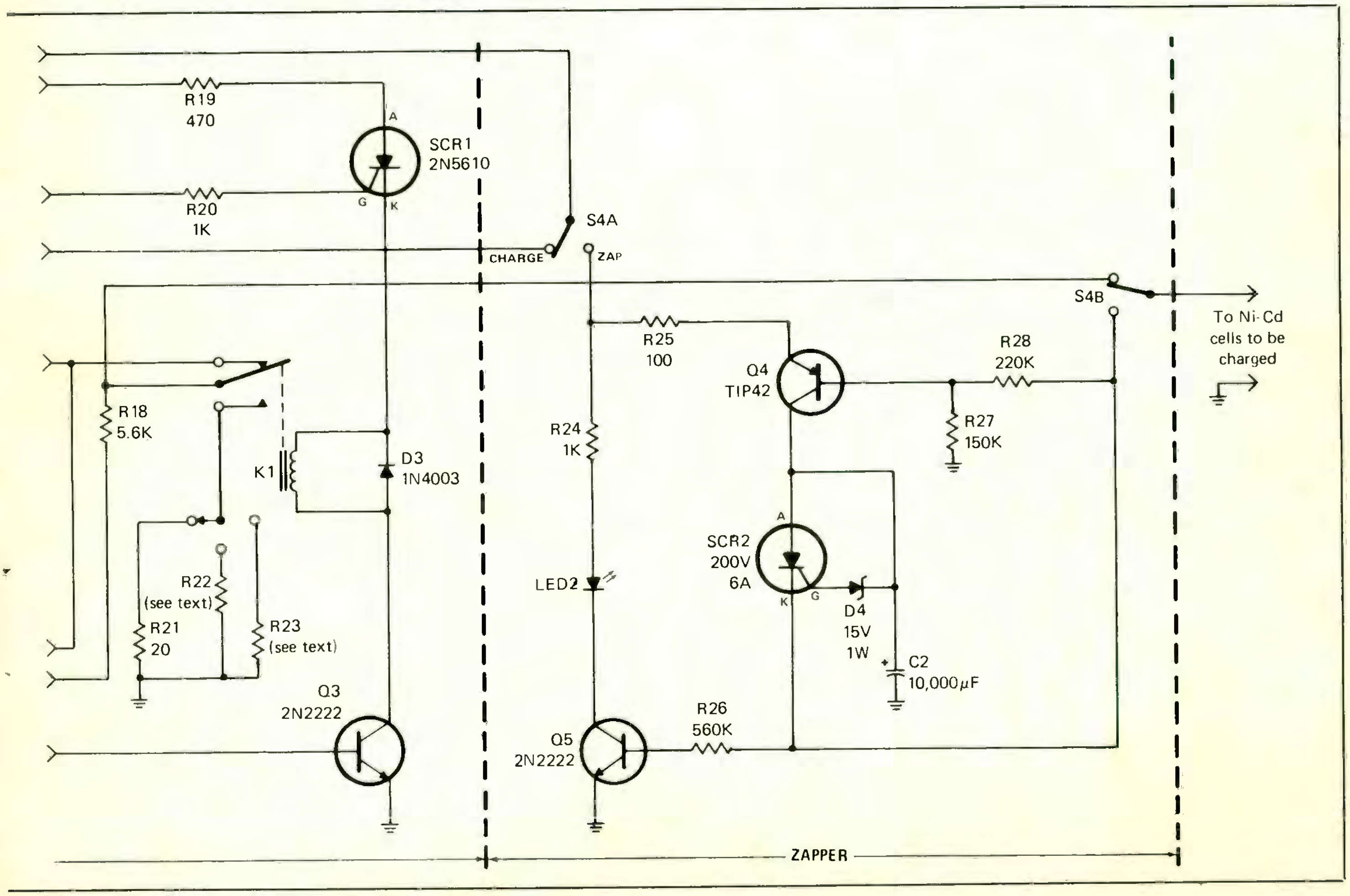
What I needed was a charger that could be programmed to the desired charge rate and a maximum voltage shutdown equal to one to ten cells. The solution was the Programmable Ni-Cd Recycler described here. Recharging Ni-Cd cells and batteries was only one of the design objectives. Another was a switch that could be used to discharge the Ni-Cds after completing a full-charge cycle to reduce and eliminate the dreaded memory effect. In this project, the battery can be switched back to charge when its discharge voltage drops to a preset 1 volt per cell and automatically recycles between charge and discharge within controlled limits. One cycle keeps Ni-Cds healthy. Repeated cycling eliminates the memory effect.

A final design objective was to incorporate into the project a "zapper" mode. The zapper clears internal "whiskers" that cause Ni-Cds to short circuit between their terminals and prevent them from taking on a charge. It also allows cells that have become reverse-charged to be restored to normal polarity. Though the zapper circuit is part of the project, it can be assembled and used separately as a stand-alone reconditioning device.

## *Problems & Solutions*

A number of effects can result in failure of nickel-cadmium cells and batteries. Chief among these are the following:

- Frequent shallow discharge before recharging that results in the dreaded "memory phenomenon," manifested as an apparent loss in a Ni-Cd's ampere-hour capacity;
- Charging to less than 1.4 volts per cell (not replacing the required 30% more energy than was discharged while the Ni-Cd was in service), which contributes to the memory phenomenon;
- Short circuiting, caused by chemi-



## PARTS LIST

**Semiconductors**

D1—5.1-volt, 1-watt zener diode
D2,D3—1N4003 rectifier diode
D4—volt, 1-watt zener diode
D5 thru D8—1N4001 rectifier diode or 50-volt, 1-ampere bridge rectifier
IC1—7815 + 15-volt regulator
IC2—7805 + 5-volt regulator
IC3—LM339 low-power quad comparator
LED1—5 volt flashing light-emitting diode (Radio Shack Cat. No. 276-036 or similar)
LED2—Panel-mount light-emitting diode
Q1, Q4—TIP42 pnp transistor
Q2,Q3,Q5—2N2222 npn transistor
SCR1—2N5610 1-ampere (50-volt or more) silicon controlled rectifier
SCR2—6-ampere, 200-volt silicon controlled rectifier (Radio Shack Cat. No. 276-1027 or similar)

**Capacitors**

C1—47-μF, 50-volt electrolytic
C2—10,000-μF, 50-volt computer-grade electrolytic
C3—1,000-μF, 50-volt electrolytic

**Resistors** (¼-watt, 5% tolerance)

R2—6,800 ohms
R4—33,000 ohms
R5,R6,R18—5,600 ohms
R7,R10,R15—3,000 ohms
R8,R9—680,000 ohms
R14,R16—20,000 ohms
R17,R20,R24—1,000 ohms
R26—560,000 ohms
R27—150,000 ohms
R28—220,000 ohms
R11—100 ohms, 1 watt (10% tolerance)
R19—470 ohms, 1 watt (10% tolerance)
R25—100 ohms, 1 watt (10% tolerance)
R12—20 ohms, 5 watts (10% tolerance)
R13—50 ohms, 5 watts (10% tolerance)
R21—20 ohms, 10 watt (10% tolerance)
R22,R23—See text
R1—10,000-ohm, 10-turn otentiometer with vernier dial
R3—10,000-ohm flat-mount pc trimmer potentiometer

**Miscellaneous**

F1—0.5-ampere slow-blow fuse
K1—12-volt dc relay with 1-ampere contacts (Radio Shack Cat. No. 275-241 or equivalent)
S1—DP3T, center-off toggle switch (Radio Shack Cat. No. 275-1545 or similar)
S2—SPDT toggle or slide switch
S3—3-position nonshorting rotary switch
S4—DPDT slide or toggle switch
S5—SPST slide or toggle switch
T1—25-volt power transformer
Suitable enclosure (see text); printed-circuit board or perforated board and soldering hardware; socket for IC3 (optional); bayonet fuse holder for F1; 4-lug terminal strip (see text); ac line cord with plug; rubber grommets; control knobs for R1 and S3; 9-volt battery snap and cell holders (see text); lettering kit; clear acrylic spray; insulating tubing; No. 6 ground lug; spacers; machine hardware; hookup wire; solder; etc.

**Note:** An etched and drilled pc board is available for $8.00 ppd from: R&R Associates, 3106 Glendon, Los Angeles, CA 90034. California residents, add state sales tax.

cal "whiskers" growing inside Ni-Cd cells that prevent the cells from taking on a charge;

• Reversed polarity of a cell in a series string, which is fully discharged first and then reverse charged by current flowing from the other cells in the string.

Fortunately, these effects are usually curable, allowing most Ni-Cds to be restored to full health. A cell or battery that has dried out due to a ruptured internal seal resulting from overheating, though, can not be cured by any known means. (The small crystals visible around their terminals easily identify a cell that has been ruptured and is beyond salvage.)

Solutions to the above effects as well as the ability to recharge Ni-Cds are provided in the Ni-Cd Recycler. The basic element of this project is its charge mode whose programmable charger can accommodate from one to ten cells. It charges each cell with a sufficient voltage to assure restoration of 30% more energy than was drained from it while in service.

A recycle mode can automatically switch fully charged cells and batteries to a discharge load, draining them until their charge drops to 1.0 volt per cell and then back to the charge mode to restore full charge. In the recycle mode, Ni-Cds are recycled continuously between full charge and discharge over their full capacity range to eliminate the memory effect. Recycling can be done just once every so often to keep Ni-Cds healthy, or it can be allowed to run as many times as needed to eliminate the memory condition.

Finally, the zapper function's high-current pulses are applied to shorted cells to burn away internal shorts and to repolarize reverse-charged cells.

### *About the Circuit*

Constant-current charging was chosen over constant-voltage charging as the fastest means of restoring the charge on a spent battery or cell without the attendant heat generated by an initial higher current. The circuit shown in Fig. 1 is the heart of the constant-current charger. Built around the common 7805 5-volt regulator, this circuit shows a single resistor, *R*, between the chip's output and common pins. The resistor sets a constant-current output that is determined by the equation: $R = 5/I$. For example, for a 50-mA charge rate, $R = 5/0.05 = 100$ ohms. Using a rotary switch as shown, different-value resistors can be connected to the various switch positions to provide different charge rates.

Supply voltage to the 7805's input terminal must be at least 5 volts

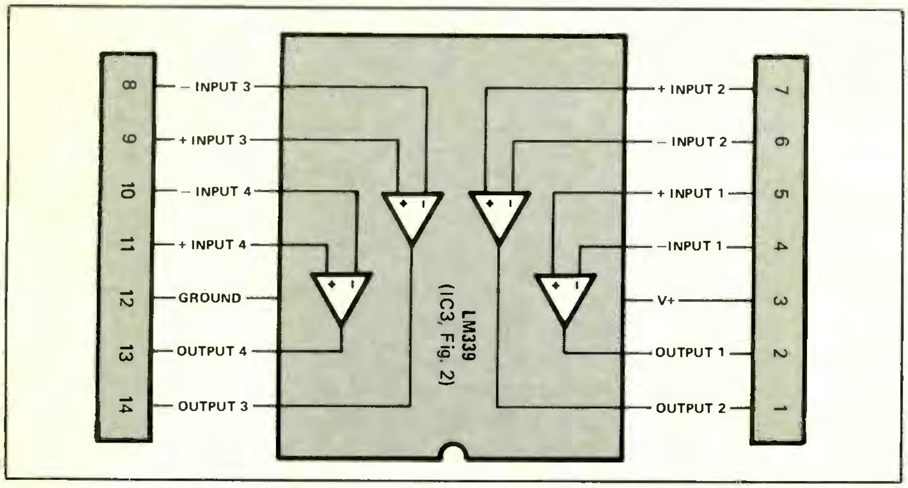



*Fig. 3. Internal details and pinouts for LM339 quad comparator.*

greater than the highest voltage required. To avoid life-reducing undercharging, the circuit should be designed to put back 30% more energy than was drawn by the cell or battery while it was in service. Therefore, the voltage on each cell must rise to 1.4 volts under charging conditions. For a 10-cell, 12.5-volt battery pack, maximum charge must be 14 volts. Therefore, minimum supply voltage to the regulator chip must be $(10 \times 1.4) + 5 = 19$ volts. To be on the safe side, it is best to use 20 to 25 volts dc.

Figure 2 shows the final design of the charger circuit. Here, +15-volt regulator *IC1* is referenced 5.1 volts above ground by zener diode *D1* to supply a regulated 20 volts dc to 5-volt regulator *IC2*. The 20-volt output from *IC1* also supplies power to the control circuitry. Cells and batteries to be charged connect to the circuit via the + and – BATTERY terminals shown at the far right.

Only three current-control resistors are switched in this circuit to provide 50, 150 and 300 mA via *R11*, *R12* and *R13*, respectively. Any number of current-control resistors can be switched to furnish a range of currents up to the 1-ampere ratings of *IC1* and *IC2* (Fig. 1). These resistors should have a wattage rating determined by the $I^2R$ formula; for a 100-ohm resistor at 50 mA charge, which actually calls for a ¼-watt resistor, use a 1-watt rating.

In Fig. 2, *R11* is always in the circuit, regardless of the position to which CHARGE RATE switch *S1* is set. To obtain the 300- and 150-mA charge rates, *R12* and *R13* are switched in parallel with *R11*.

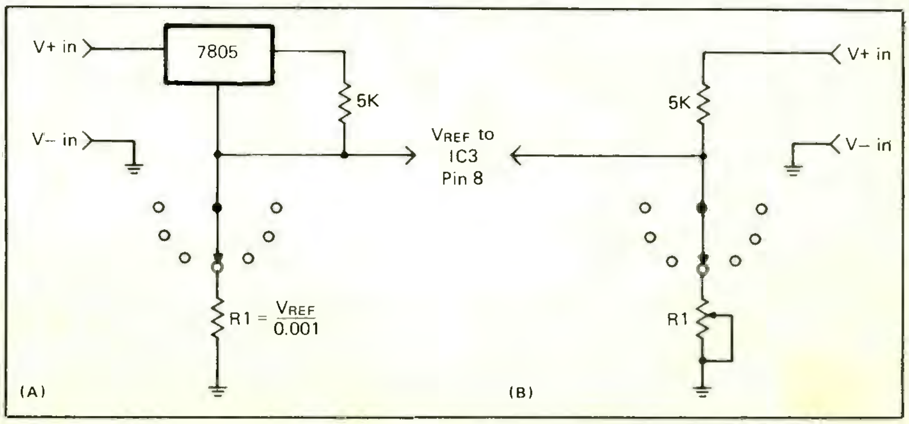
In the charge/discharge control circuit, two sections of quad comparator *IC3* (see Fig. 3 for internal details and pinouts for this quad comparator) separately detect the programmed full charge and full discharge voltage limits. In the charge mode, V MAX control *R1* sets a reference voltage on the inverting (–) input of the first comparator in *IC3* at pin 8. This reference voltage is equal to 1.4 times the number of cells. The noninverting (+) input at pin 9 of this comparator monitors the output voltage across the cell or battery being charged. When the charge exceeds the reference set by *R1*, the comparator's output at pin 14 goes high, producing 20 volts that biases off *Q1* and disables the charge current to the cells. The 20 volts also turns on *Q2* and END OF CHARGE light-emitting diode *LED1*.

A 10-turn precision potentiometer with vernier dial is recommended for *R1*. However, a single-pole rotary switch and a number of fixed-value resistors can be substituted for the voltage reference portion of the circuit (Fig. 4). Figure 4A employs another 7805 to supply a constant 1 mA to resistors of selected fixed values. The values of these resistors are calculated according to the formula $R = V_{ref}/0.001$. For example, for $V_{ref} = 8.4$ volts, $R = 8{,}400$ ohms.

If you have a problem finding resistors of the exact calculated values, various standard values can be wired in series or/and parallel configurations as needed. Alternatively, you can wire into the circuit separate 10,000-ohm trimmer potentiometers for each switch position, as in Fig. 4B, and set them for the desired reference voltages.

Returning to Fig. 2, resistor *R8* sets up conditions so that when the battery (off charge) drops down about 0.2 volt, output pin 14 of *IC3*

*Fig. 4. Alternative voltage references.*



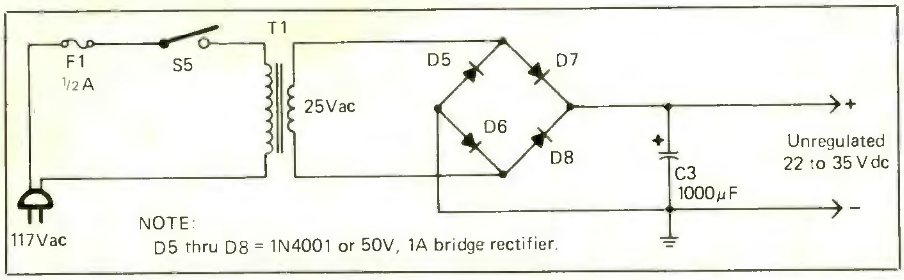



*Fig. 5. Power supply for Fig. 2.*

goes low, *Q1* switches on the charging current, cutting off *Q2* and extinguishing *LED1*. Circuit status then remains unchanged until the voltage across the cells or battery being charged rises above the reference level set by *R1*. This cycle then repeats, with the charge pulsed on and off, rather than tapering down, with decreasing charge pulses as the battery tops off. The pulsing final charge is very effective in bringing the battery to full charge without creating an overvoltage condition.

In operation, even when cells are left for several hours on pulsating charge, there will be no discernible heating of the cells. With *S2* set to CHARGE, *LED1* will flash when the battery is fully charged.

With *S2* set to RECYCLE, the first time the battery voltage causes *IC3* to switch to a high output at pin 14, *SCR1* turns on. This closes *K1*'s lower contacts, completing a circuit from the battery or cell to ground through *R17*. This resistor then discharges the battery until the voltage drops below the reference at the pin 4 inverting input of the second comparator in *IC3*, set by V MIN control *R3* (V MIN is equal to 1 volt times the number of cells being charged).

When output pin 2 of *IC3* is high, *Q3* conducts. When battery voltage monitored by the noninverting input at pin 5 of *IC3* drops below the V MIN reference at pin 4, output pin 2 goes low. This deenergizes *K1* and switches the battery back to the charge output. Interruption of relay coil current also switches off *SCR1*.

Trimmer *R3* and resistors *R2* and *R4* can set the discharge limit to 70% of the charge limit. Since *R3* is supplied from the wiper of *R1*, the discharge limit will always track the charge limit set by *R1*. Hence, *R3* must be adjusted only once and is, therefore, a hidden set-and-forget trimmer control.

Shown in Fig. 5 is the simple ac-line-operated power supply for the Fig. 2 circuit. This circuit delivers an unregulated 22 to 35 volts to the charger circuit. Regulation is accomplished by *IC1* and *IC2* in Fig. 2.

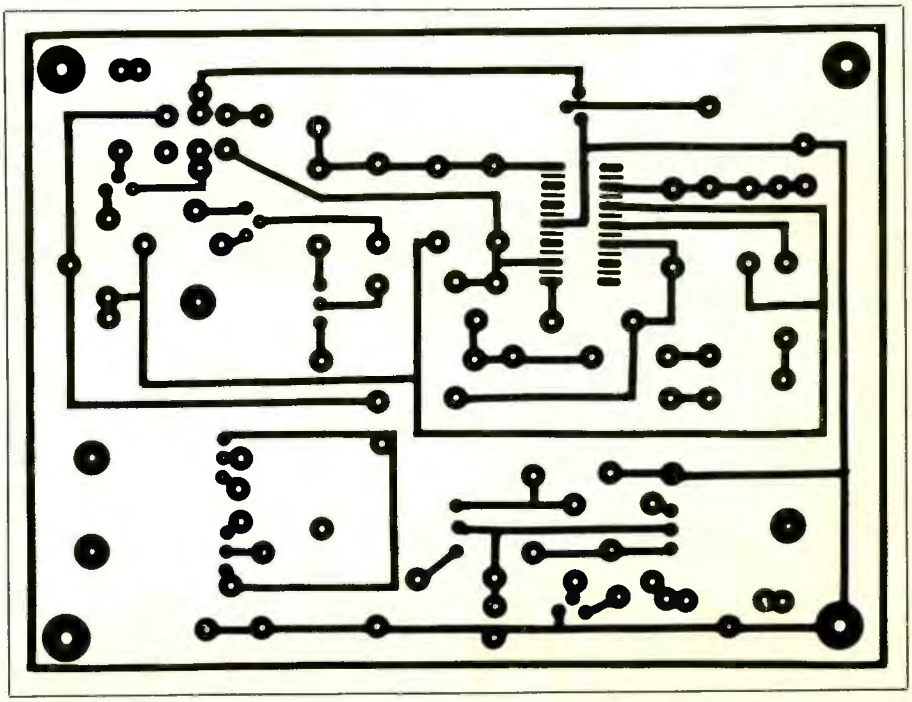
Burning away internal whiskers by discharging a large capacitor like the 10,000 μF specified for *C2* in Fig. 2 through the "bad" cell is effective, though it can require a considerable number of discharges to fully clear a short. Connecting one or more good Ni-Cd cells across the shorted cell may work but could result in destructive venting if a heavy current is sustained for too long a time.

Repeated short-duration, high-energy pulses delivered to a shorted cell clears whiskers without attendant potential damage to the cell being treated. Short clearing in this project is accomplished with the automatic zapper circuit consisting of *C2*, *R4*, *Q5* and *SCR2* in Fig. 2. (*Warning*: Be sure to use the zapper function with only *one* Ni-Cd cell at a time!)

With *S4* set to ZAP, regulated 20 volts dc charges *C2* through *Q5*. When the charge reaches 15 volts, zener diode *D4* conducts and triggers on *SCR2*, causing *C1* to discharge through the cell connected to the output terminals of the project in a short burst of high energy.

Feedback to the base of *Q5* causes this transistor to disable the charging current until *C2* is fully discharged and *SCR1* stops conducting. Then

*Fig. 6. Actual-size etching-and-drilling guide.*



when *Q5* conducts again, *C2* charges once more. The cycle repeats as long as needed to restore the shorted cell.

CONDITION light-emitting diode *LED2* is normally off, since the cell is a direct short circuit across it, but it flashes each time a pulse is applied to the cell. When the cell's internal short is cleared, *LED2* lights continuously to signal that the cell has been cleared of whiskers.

In addition to clearing internal short circuits, the zapper function will repolarize cells that have become reverse charged. Bear in mind, though, that not all such cells can be rejuvenated in this manner. Some are just plain worn out from use. Just connect the cell across the project's output terminals in proper polarity and run the zap function until *LED3* lights continuously and then switch over to normal charging until the cell's potential on charge measures the full 1.4 volts.

## Construction

Most of the circuitry shown in Fig. 2 can be assembled on a small printed-circuit board you can make yourself using the actual-size etching-and-drilling guide shown in Fig. 6. If you wish, you can purchase a ready-to-wire board from the source given in the Note at the end of the Parts List. Alternatively, you can assemble the circuit on perforated board with the aid of suitable soldering hardware.

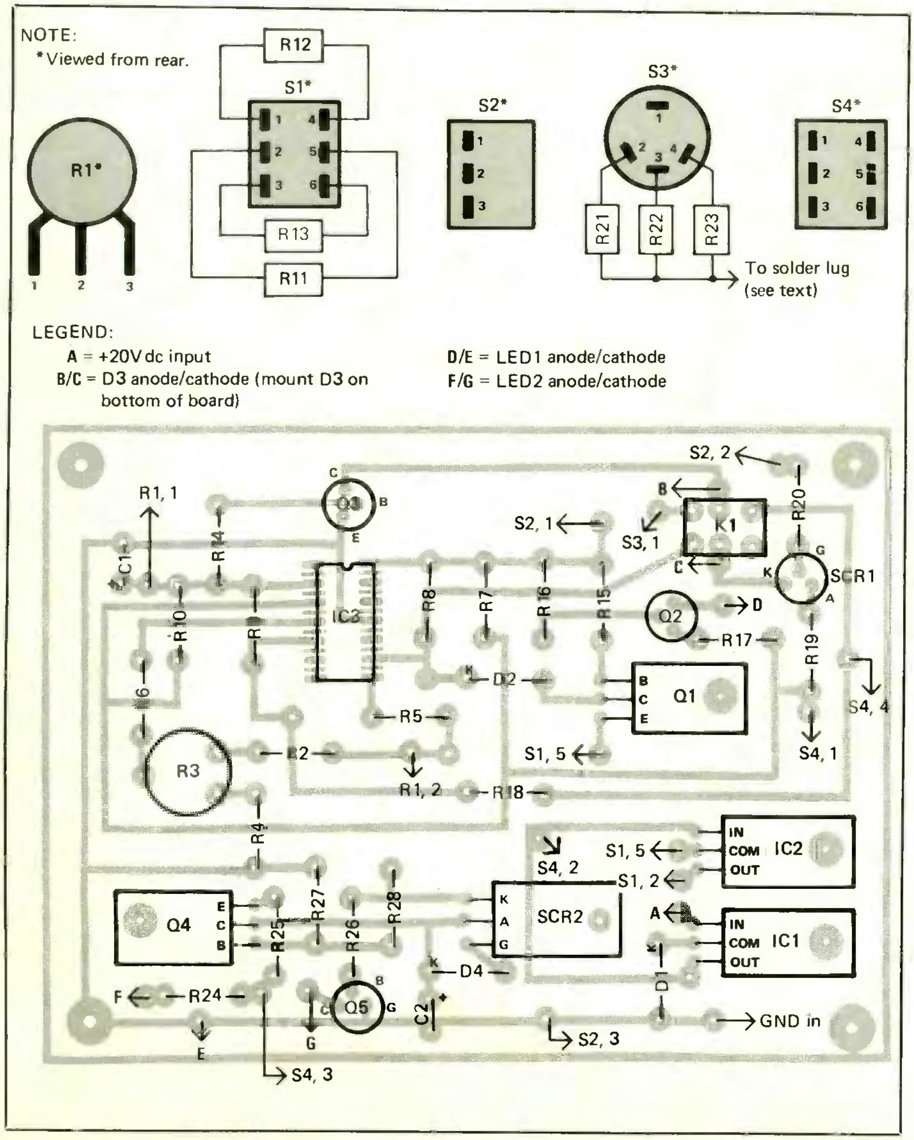
Light-emitting diodes *LED1* and *LED2*, 10-turn potentiometer *R1* and the various switches mount on the front panel of the box in which the project is housed. Wire the Fig. 2 circuit exactly as shown in Fig. 7, starting with the resistors and diodes and working up to the largest components. Note that *D3* mounts on the bottom of the board, *after* installing *K1*. A socket for *IC3* is optional but recommended. Make sure as you install *C1*, the diodes, transistors and ICs that they are properly oriented before soldering their leads into place.

Mount all power resistors with 1-watt or higher rating so that there is ⅛" to ¼" of space between them and the board's surface to allow for air circulation. Finish board wiring by installing and soldering into place suitable lengths of prepared hookup wire at the locations that are to interconnect with off-the-board components. Use heavy-duty color-coded stranded hookup wires for the lines to the power supply and output terminals and for the wiring between *S4B* and *K1*'s toggle contact.

For convenience, it is a good idea to use a pair of front-panel-mounted color-coded jacks or 5-way binding posts, connected to the project's output terminals, to allow you to monitor battery voltage during charging with an external meter. The battery connectors and holders can be installed in the project case, along with the rest of the circuitry. If you decide to use a separate box in which to house the battery connectors and holders, mount a suitable jack on the rear panel of the main project to provide a means for connecting the external box to it.

Drill all required mounting holes,

*Fig. 7. Wiring details for pc board and potentiometer R1 and switches.*

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including a hole for POWER switch *S5*. If you are using a metal enclosure, deburr all holes. Now, dry-transfer label the various switches according to function and position, the LEDs and 10-turn vernier-dial potentiometer *R1*. Then spray three or four *light* coats of clear acrylic over the lettering, waiting for each coat to dry before spraying on the next.

Mount the LEDs on the front panel via either clips or small rubber grommets. Then mount *R1* via its vernier dial and the various switches, orienting them as shown in the details given in Fig. 7. Note that *R11*, *R12* and *R13* wire directly across the lugs of *S1* and that *R21*, *R22* and *R23* wire to the position lugs of *S3*. In the latter case, tie together the free ends of the resistors and terminate the common connection with a length of heavy-duty stranded hookup wire.

Mount the circuit board in place, using ½″ spacers and ¾″ machine hardware. Place a No. 6 ground lug under one of the board's screws nearest the front panel. Then connect the free ends of the wire coming from the board to the indicated lugs of *R1* and switches, trimming their lengths as necessary to keep the project neat. Tie the free end of the wire connected to the common junction of *R21*, *R22* and *R23* to the solder lug and solder the connection.

Before connecting and soldering the wires to the leads of the LEDs, slip over them lengths of insulating tubing. Then push the tubing up to cover the exposed metal of the leads to prevent them from shorting to each other or the chassis.

Securely bolt *C2* and *T1* to the floor of the enclosure. If you are using discrete rectifier diodes for *D5* through *D8*, secure the 4-lug terminal strip in place with one of the screws used to mount *T1* in place and, referring back to Fig. 4, wire the diodes to the lugs. (Make sure that you select a terminal strip whose lugs are isolated from its mounting tabs.) Otherwise, mount the bridge rectifier assembly and fuse holder on the rear wall of the enclosure. Pass the free end of the ac line cord through a rubber-grommet-lined hole and tie a knot in it about 6″ from the inside end. Finish wiring the power supply circuit according to Fig. 5.

**Capacity and Charge Rate for Popular Nickel-Cadmium Cells**

| Size | Capacity mAHr | Standard mA | Charge Hrs. | Quick mA | Charge Hrs. |
|---|---|---|---|---|---|
| N | 150 | 15 | 15 | 38 | 6 |
| AAA | 180 | 18 | 15 | 45 | 6 |
| 1/3 AA | 110 | 11 | 15 | — | — |
| 2/3 AA | 250 | 25 | 15 | 75 | 4.5 |
| AA | 500 | 50 | 15 | 150 | 4.5 |
| 1/2 C | 600 | 60 | 15 | 150 | 6 |
| SC | 1,200 | 120 | 15 | 300 | 6 |
| C | 1,800 | 180 | 15 | — | — |
| D | 4,000 | 400 | 15 | — | — |
| F | 7,000 | 700 | 15 | — | — |

If the battery holders and connectors are to be external to the main project, terminate their interconnect cable with a plug to match the project-mounted jack. You can start from scratch making an enclosure for the connectors and holders, or you can cannibalize a commercial battery charger.

Your choice of battery holders depends on your needs. If you want a universal charger, design the system to handle all possible types of batteries and cells.

## Calibration and Use

To calibrate 10-turn V MAX control *R1*, connect an accurate voltmeter between the control's wiper and ground terminals. Prepare a two-column calibration chart with headings of "Number of Cells," "Volts" and "Setting." Under the first heading, write the numbers 1 through 10 in a vertical column and under "Volts" the figures 1.4, 2.8, 4.2, 5.6, 7.0, 8.4, 9.8, 11.2, 12.6 and 14.0. Now adjust *R1* for meter readings of each of the voltages entered in the second column, filling in the vernier dial settings at which each occurs in the appropriate location under the "Setting" heading in the table. Tape the calibration table to the project's enclosure for ready reference.

To calibrate the deep discharge limit, first set *R1* for a meter reading of 8.4 volts. Then connect the voltmeter between the wiper terminal of V MIN control *R3* and ground and adjust this trimmer for a reading of 6.0 volts. No further adjustment of *R3* is required since it tracks *R1*.

Discharge load resistor *R21*'s 20-ohm value gives discharge rates and times that vary according to the voltage and capacity of the battery or cell(s) connected to the Recycler. With a 10-cell 12.5-volt, 500-mAHr pack, this load discharges at a 625-mA rate in about 1 hour. A 1.25-volt, 500-mAHr single AA cell will discharge at a 62.5-mA rate in approximately 8 hours, while a single 4,000-mAHr D cell will discharge at the same rate in 64 hours—which is excessively time-consuming for practical recycling!

If you intend to recycle low numbers of high-capacity cells, you may want to switch in some lower-resistance loads via *S3* to speed up the process. The values of discharge resistors *R22* and *R23* are calculated using the formula R = E/I, where *R* is in ohms and *E* is total voltage and *I* maximum allowable discharge current for each cell and battery combination. Maximum discharge current should not exceed cell capacity. (See the Table for capacity and charge rate information for various popular Ni-Cd cells.) Use the P = IE formula to determine wattage. Just make sure to use resistors with high enough wattage ratings to safely handle the current flow.

Use of the Recycler feature is not limited to HT packs. Batteries from electric razors, emergency lights, soldering irons, etc., all tend to be maintained on trickle charge until needed and are, thus, susceptible to memory problems. By periodically exercising them with this project, they can be restored to full capacity.

When first recycling a battery suffering from the memory effect, best results are obtained by using a low charge rate, such as 50 mA for a 500-mAHr AA cell.

When using the Zap mode, remember that the CONDITION LED will light to indicate that the short has cleared, but you must make sure that the cell remains in this condition. To do this, continue to zap the cell for 10 to 30 minutes (the time being in proportion to how long it took to initially burn away the internal short) after *LED2* lights continuously. This assures that the cell is fully restored before it is put back into service. Also, after zapping, immediately put the cell on a low charge cycle until you measure 1.4 volts across it during charging. (It will initially measure about 1.25 volts at the end of zapping.) This ensures that whiskers will not grow back in just a few days.